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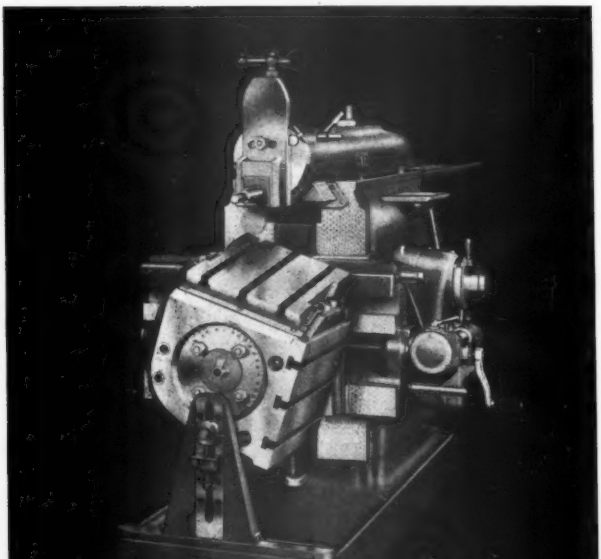


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# CUTTING TOOLS

*Paper presented to the Institution, Coventry Section, by Dr. G. Schlesinger, Director, Research Department of the Institution.*

TO read a paper concerning cutting tools in Coventry, the centre of the machine tool industry and engineering production is rather like carrying coals to Newcastle. In spite of this handicap I shall try, as experimenter and user, to give a review of the results which have been arrived at during the last five years concerning the manufacture and use of high speed cutting tools.

The three demands on modern tools are : (1) speed ; (2) accuracy ; (3) long life—*i.e.*, economy for the user.

Achievement of these three conditions depends not only on the tool but on the resistance of the material to be machined, its tensile strength, hardness and toughness. Increase in resistance of the material is finally reflected back to the machine tool, which must be designed for greater power and speed and manufactured more accurately. Attempts to speed up old machines to exploit high-speed tools must be made carefully, as many break-downs are probable, which may outweigh the benefits.

The super-rapid steels as well as the cemented carbides are now used for all cutting tools : lathe and planer tools—single lips ; drills—two lips ; counterbores, reamers, and milling cutters—multiple lips (Fig. 1). If we compare the chemical constituents of the high-speed steels of the leading firms of the world (Fig. 2) we find that the percentages of the five main components, carbon, tungsten, cobalt, vanadium, and chromium are about the same. Molybdenum, tantalum, titan and manganese are less used.

In outward appearance there is no difference between a cemented carbide tip or a cobalt-tungsten tip. The manufacture and treatment of these tools by brazing, welding, hardening, tempering, grinding, lapping, honing, diamantiding, are very similar and can be discussed simultaneously. An essential difference exists, as the high-speed steels can be butt-welded instead of brazing tips on shanks, and this has some important advantages.

Butt-welded cobalt-tungsten tools make contact with the grinding wheel with uniform material, whereas tipped tools need special grinding precautions, as the shank of mild steel and the tip of high-speed steel in combination will easily glaze a grinding wheel selected for the tip or wear it down quickly.

*December 13, 1938 (Vol. XVIII, No. 2, February, 1939.)*

The welded tool is superior in strength and will, in most cases, stand for more re-grinds before being discarded. It is not subject to the objectionable splitting that occurs with tipped tools. Almost the whole of the high-speed steel portion may be ground away, leaving only the shank material. With regard to the strength of the butt-weld in these tools, tests to destruction have proved that the weld shows greater strength than the high-speed end of the tool.

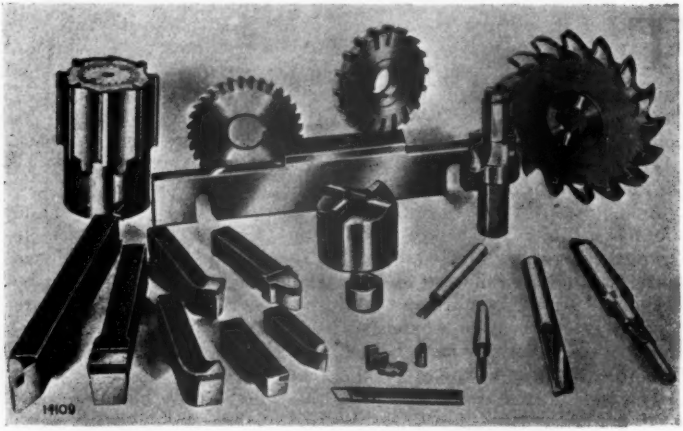


**Fig. 1.—Tipped tools of all kinds (Ardoloy).**

| No. | Country | C | Tu | Co | Va | Mo | Cr | Mn |
|---|---|---|---|---|---|---|---|---|
| 1 | Great Britain ... | .6 | 20 | 15.16 | 2 | — | 5 | — |
| 2 | Great Britain ... | .8 | 18 | 15 | 1 | — | 5 | — |
| 3 | America ... ... | .72 | 20.5 | 12.3 | 1.3 | .6 | 4.3 | .2 |
| 4 | Germany ... ... | .55 | 17.19 | 17 | 1.13 | .5 | 4 | — |
| 5 | Germany ... ... | .85 | 19 | 15 | 1.5 | .6 | 4.3 | — |
| 6 | Luxemburg ... | .9 | 18 | 10 | 1.8 | .3 | 5 | .5 |
| 7 | Czechoslovakia ... | .6 | 18 | 18 | 1.9 | 1 | 4.2 | — |
| | Super high-speed steels: Tu Co Va Mo. | | | | | | | |

**Fig. 2.—Chemical components of high-speed tools.**

## Brazing Tips to Shanks (Fig. 3)

The shank of the tool is made of high grade steel usually containing 0.4 to 0.7% carbon. Pure copper is employed as a brazing medium, the flux suggested is unfused borax. The copper should be rapidly melted, and the temperature of the furnace should be maintained at 1,150° to 1,250°C. with a reducing-hydrogen atmosphere. Every

care should be employed to ensure that the flame does not impinge directly on the tip.

It is advisable to preheat the shank to 800°. The tip is made a very good fit on its seating ; A to G in Fig. 3 show faulty fits. Both shank and tip are carefully degreased. Carbon-tetra-chloride can be recommended, but petrol and paraffin are unsuitable. When the copper is seen to liquefy, the tip is moved slightly on its seating to

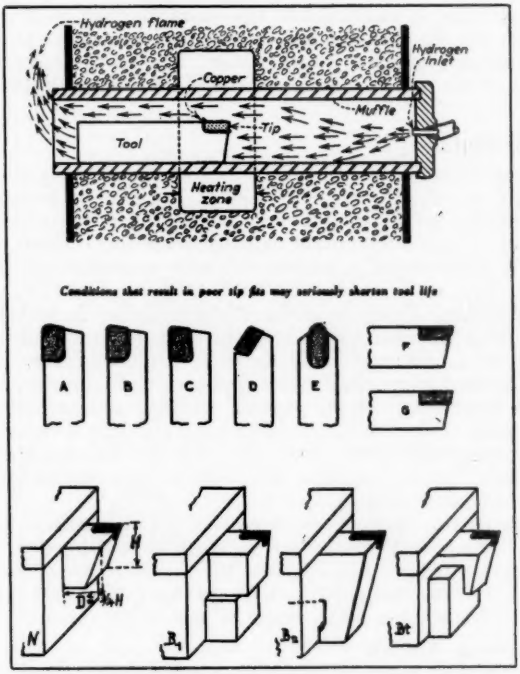



**Fig. 3.—Brazing furnace. Poor setting. Support of tools.**

make sure of a satisfactory joint. After this the tool should be removed from the furnace and the tip gently pressed into place. The brazed tool must then be dipped in powdered charcoal to ensure slow cooling without contact with the air. The tipped tool should be supported very rigidly in the tool-post as shown by the lower diagrams in Fig. 3.

The clamping methods most used are :—

N.—Free hanging tool, D = $\frac{3}{4}$ H. $B_1$—Support from underneath. $B_2$.—Special shank with angle support. Bt.—Support from underneath and sidewise.

The more rigidly the tool is supported the longer is its life.

### Grinding

Wet grinding is recommended and should be carried out with extreme care. Coolant must be supplied copiously and constantly. If dry grinding is unavoidable, the operator must make perfectly sure that the tip does not become too hot, and above all he must avoid cooling it suddenly with water. This is the most frequent cause of cracks, which will immediately lead to a break-down of the tool.

### Cutting Fluids

Cutting fluids increase the life of the tool considerably in all cases, especially in cutting *steels* of all kinds. But equally as in grinding the tool edges before using them in a lathe, water must be supplied constantly ; any interruption endangers the tool. Good compositions are mixtures of a mineral oil with a sulphurised fatty oil, made of 20% saponifiable oil ; 1.8% total sulphur ; 78% mineral oil (remainder). To minimise the risk of chipping, the tool should be ground from the tip to the body of the tool, the front and side faces being ground first, and lastly the top. Only moderate pressures should be used in grinding. The application of undue force results in rapid wheel wear with the possible cracking and chipping of the cutting edge of the tool. Therefore hand grinding is recommended with the use of rest and angle fixtures (Fig. 4). The shank should be considerably larger than that of a solid or butt-welded high-speed tool for the following reasons :—

(1) The cutting of the recess to receive the tip weakens the shank. (2) The cutting temperatures are higher, when cutting dry. (3) The cutting pressures are greater, since the top rakes are generally less on account of the design of the tool. (4) Vibrations and deflexions, caused by too weak a shank, must be kept at a minimum.

### The Cutting Angles

The reciprocal influence of the tool and the material to be cut is shown by the Table (Fig. 5). *Front and side clearance* angles should be just great enough to allow a free cutting action : from 4 to 7° is common for cutting steel. A large *top rake* gives an acute cutting angle and reduces the component forces acting on the tool. Large rakes are used for the softer metals but these cannot be employed when cutting steels, as the latter offer a greater resistance to penetration. The cutting edge must always sustain the cut when the tool has entered. The table shows the American and German

practice taken from their respective publications. More than 10 leading British steel and tool-making companies have published booklets and catalogues giving information which could be used as a very good basis for standardising British cutting-angles for lathe and planer tools. Only the top rakes are scheduled in Fig. 5.* American and British figures cover 12 groups of material, the Germans have six, but regarding the important top rake angle

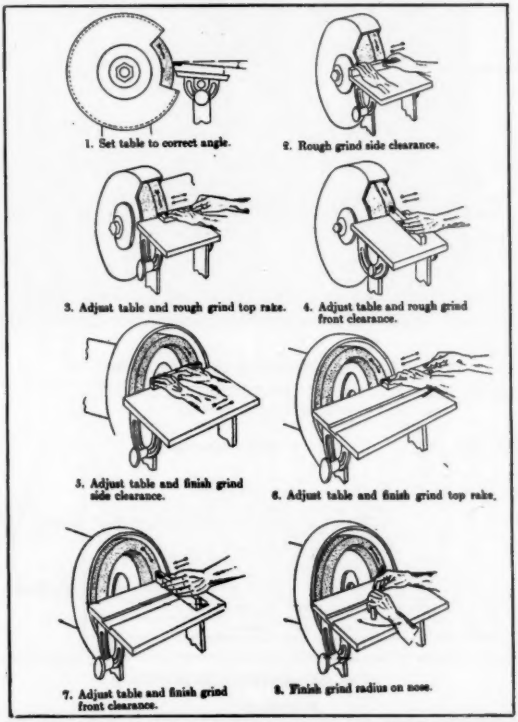
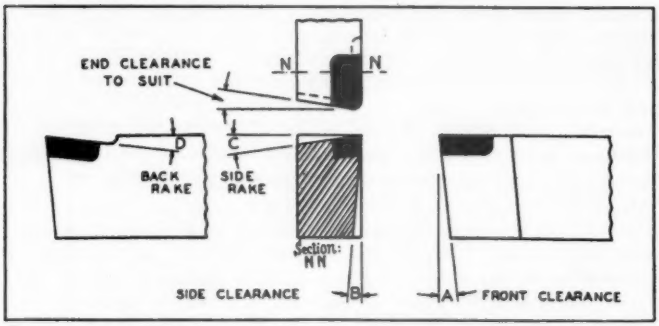

1. Set table to correct angle.
2. Rough grind side clearance.
3. Adjust table and rough grind top rake.
4. Adjust table and rough grind front clearance.
5. Adjust table and finish grind side clearance.
6. Adjust table and finish grind top rake.
7. Adjust table and finish grind front clearance.
8. Finish grind radius on nose.

**Fig. 4.—Hand grinding of tipped tools on adjustable table. (Carborundum Co.).**

($C,\gamma$) the Americans have eight to ten, and the British and Germans six different values, which differ from each other considerably.

It is essential to have the cutting angles correctly ground. Therefore all tools coming from the grinding department ought to be checked either by fixed angle gauges or by a universally adjustable angle measuring instrument (Fig. 6a and 6b).




| Nature of material to be machined | Front clearance "A" | Side clear. "B" | Side rake "C" | Back rake "D" |
|---|---|---|---|---|
| Cast iron—soft ... ... ... | 3 to 5 | 2 to 4 | 4–8 | 0–4 |
| ,, hard ... ... ... | 3 ,, 5 | 2 ,, 4 | 3–6 | — |
| Semi-steel ... ... ... ... | 3 ,, 5 | 2 ,, 4 | 3–6 | — |
| Cast nickel iron ... ... ... | 3 ,, 5 | 2 ,, 4 | 3–6 | — |
| Chilled cast iron ... ... ... | 3 ,, 5 | 2 ,, 4 | 3–6 | — |
| Malleable iron ... ... ... | 3 ,, 5 | 2 ,, 4 | 4–8 | 0–4 |
| Yellow brass ... ... ... ... | 4 ,, 6 | 3 ,, 5 | 0 | — |
| Ordinary bronze ... ... ... | 4 ,, 6 | 3 ,, 5 | 4–8 | — |
| Bronze alloys ... ... ... ... | 4 ,, 6 | 3 ,, 5 | 4–8 | — |
| Cast aluminium ... ... ... | 6 ,, 8 | 3 ,, 5 | 10–20 | 10–20 |
| Aluminium alloys ... ... ... | 6 ,, 8 | 3 ,, 5 | 10–20 | 10–20 |
| Non-metallics... ... ... ... | 6 ,, 8 | 3 ,, 5 | 6–10 | 2–6 |

**Fig. 5.—Clearance angles. U.S.A.**

TABLE 1A. TOOL ANGLES FOR VARIOUS MATERIALS

| Clearance Angle α deg. | Wedge Angle β deg. | Top Rake Angle γ deg. | Class of Material to be Machined |
|---|---|---|---|
| 6 | 84 | 0 | Chilled Iron and Very Brittle Brass and Bronze |
| 8 | 74 | 8 | Steel and Cast Steel of more than 45 tons per sq. inch Tensile Strength. Hard Cast Iron with Brinell Hardness No of more than 115 tons per sq. inch. Cast Brass, Bronze and Yellow Brass |
| 8 | 68 | 14 | Steel and Cast Steel of 32 to 45 tons per sq. inch Tensile Strength. Cast Iron of Brinell Hardness No of less than 115 tons per sq. inch. Soft Yellow Brass. |
| 8 | 62 | 20 | Steel and Cast Steel of 22 to 32 tons per sq. inch Tensile Strength |
| 8 | 55 | 27 | Tough and Soft Bronze. Very Soft Steel |
| 10 | 40 | 40 | All Soft Metals [Pure Aluminium |

German Practice

**Fig. 5a.—German standards.**

| Material | Top rake deg. |
|---|---|
| Mild steel (28 tons per sq. in.) ... ... ... ... ... ... ... ... | 15 |
| ,, (40 ,, ,, ) ... ... ... ... ... ... ... ... | 10 |
| ,, (50 ,, ,, ) ... ... ... ... ... ... ... ... | 8 |
| Nickel-chromium and alloy steel (50 tons per sq. in.) ... ... ... ... | 5 |
| ,, ,, ,, (80 ,, ,, ) ... ... ... ... | 3 |
| Cast steel (60 tons) ... ... ... ... ... ... ... ... ... | 5 |
| Manganese steel ... ... ... ... ... ... ... ... ... ... | 3 |
| Soft cast iron ... ... ... ... ... ... ... ... ... ... | 10 |
| Medium cast iron ... ... ... ... ... ... ... ... ... ... | 5 |
| Hard cast iron (chilled) ... ... ... ... ... ... ... ... ... | 3 |
| Vulcanite, bakelite ... ... ... ... ... ... ... ... ... | 25 |
| Copper, aluminium ... ... ... ... ... ... ... ... ... | 25 |

**Fig. 5b.—British publication on top rake of cemented tools. June, 1938. Inst. of Mechanical Engineers.**

For reasons of economy the number of angles chosen for the different materials has a decisive effect on the possibility of equipping the workmen of a turning department with the necessary cutting tools. Taking only six sets of angles and 25 different shapes —there are some more variables—then there might be 150 tools for

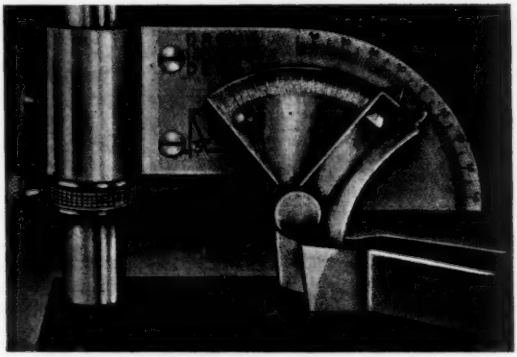


Fig. 6a.—Universal measuring instrument for tool angles.

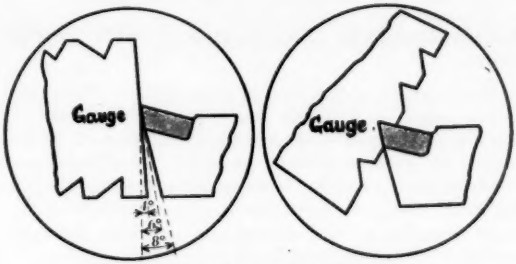



Fig. 6b.—Measuring templets.

each man (outside, inside, roughing, finishing, facing, parting off, recessing, rounding, threading, etc.). Not all of them are necessary for each shop, of course, but it is a real study* to find the economic minimum for each department with a reasonable expenditure.

In roughing, it is of great importance that the plan angle $x$, Fig. 7, is rightly chosen, otherwise considerable vibration is set up.

* *Journal of the Production Engineers, Vol. XVII. October, 1938.*

The size of this angle has an influence on the vertical cutting force, as well as on the shank force—both are decreased as the angle is increased, while the component of feed naturally increases slightly.

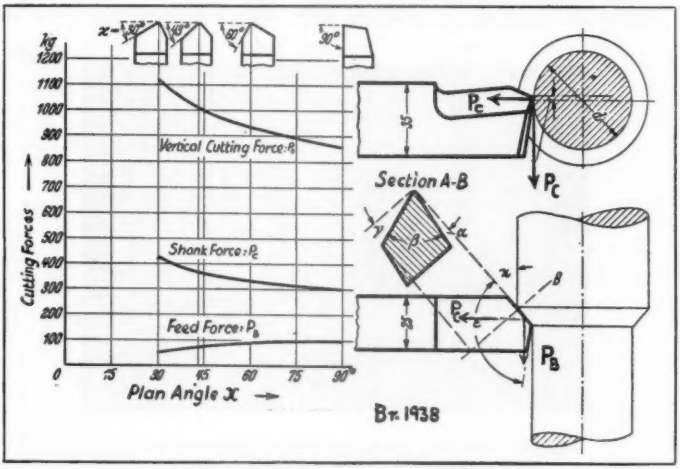



Fig. 7.—Influence of "plan" angle $x$.

**Rules for the Handling of Cemented Carbide Tipped Tools: Vibration.**

(1) No irregularity of the feed is permissible. Rack and pinions mostly have play, and screw and nut feeding mechanisms are preferable. (2) The tool must be firmly supported as near to the cutting edge as is conveniently possible. (3) There must be no chatter or vibration in either the machine itself or the piece being machined.

(4) There must be no end movement or lift in the main spindle bearings.

(5) The driving belt or motor must provide sufficient power without any slipping of the belt or clutch. The least stoppage of the work piece breaks the tool.

(6) When used on planing machines the tool boxes should be provided with a positive lifting device to clear the tool during the return stroke.

The shape of the chip depends primarily on the cutting speed. The three types of chip, tear-type, shear-type or flow-type are, however, only distinguished by the effect on the surface. Modern tools are hard enough to stand heat and strain. The cutting surface

of the tool must be kept clean. Avoid the built-up edge, which is always "tearing," and you will have a good result! In cutting steel high speed and good lubricants are the two best remedies against rough surface finish. From 300 feet upwards we do not find a built-up edge according to our latest tests made in December 1938 at 3,000 feet on tough chromium-nickel steel with 3.5% Ni. and 60 to 75 tons/sq. in. (for case-hardening purposes).

There is a German patent, No. 523594/1931, which states that over 600 m/min. (2,000 feet) the structure of the chip is mainly changed to a flow-type and that with the same type of tool the specific cutting power is considerably reduced. Both statements do not correspond to the facts. We compared the structure of chips taken at 3,000 feet/min. under the microscope with the old photographs published by Professor Thime Petersburg, 1877, and found no essential difference. And we measured the power and the cutting forces without finding any remarkable difference when reduced to specific coefficients to allow for the difference in conditions. The economic result of production research concerning modern tools is in fact marked by the three above-mentioned demands on modern tools: speed, accuracy, and long life (economy and efficiency).

Fig. 8 shows simple and complicated samples, small and big, of all kinds of material: copper, aluminium, mild steel, alloyed steel, cast-iron, chilled iron, steel casting. The allowances and the times of machining inscribed on the samples show the enormous reduction in the cutting times, whilst the accuracy and the appearance of a surface turned at high speed begins seriously to compete with a ground finish.

## Grinding Cemented Carbide Tipped Tools

Ordinary emery grinding wheels with peripheral speeds of from 4,000 to 6,000 ft. per min. are used for wet grinding cobalt tungsten tools. To grind cemented carbide tipped tools generally, two and frequently three operations are used, roughing, finishing and fine-finishing.

For roughing the tip a soft carborundum wheel (green crystolon) with copious water is generally used. Finish grinding is carried out on specially graded wheels. Final finishing should be effected with diamond wheels, some of which are shown in Fig. 9. No other method but diamond grinding (not lapping) will produce a perfect cutting edge. Diamond grinding of the cutting edge is absolutely essential for tools which are intended to cut synthetic resins, insulating materials, and for any finishing operations. The diamond grinding wheels are rapid stock removers, but it is not recommended that they should be used for rough grinding. First the shank, then the tip should be rough ground, first on a coarse free cutting wheel with special

grit and grade and ample water. The risk of cracking is negligible with a diamond wheel, since these wheels are so free cutting. To meet these conditions specially designed grinding machines, very rigid, without any play, and with two or more wheels of different grades have been put on the market.

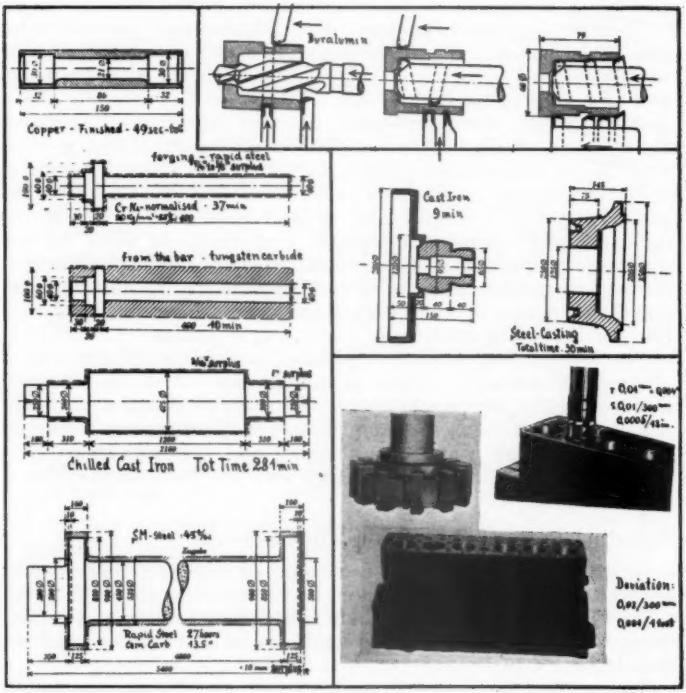



**Fig. 8.—Speed, precision, efficiency of cemented carbide tipped tools.**

Diamond wheels are made in a variety of cup and dish wheel shapes, with different diamond concentrations and bonds either of a bakelite or a metallic base such as steel or copper. Peripheral speeds between 3,600 and 5,500 feet/min. are employed. Diamond wheels are also manufactured in the form of cut-off wheels down to 0.02 in. (0.5 mm.) width, whilst the crowns are used to bore the hardest granite as well as to cut tungsten carbide tips.

The *diamond single-point tool* has been used for more than thirty years for machining non-ferrous metals and alloys such as copper, brass, bronze, white metals, aluminium, duralumin, elektron, silumin, silver, gold, platinum, vulcanite, ebonite and various

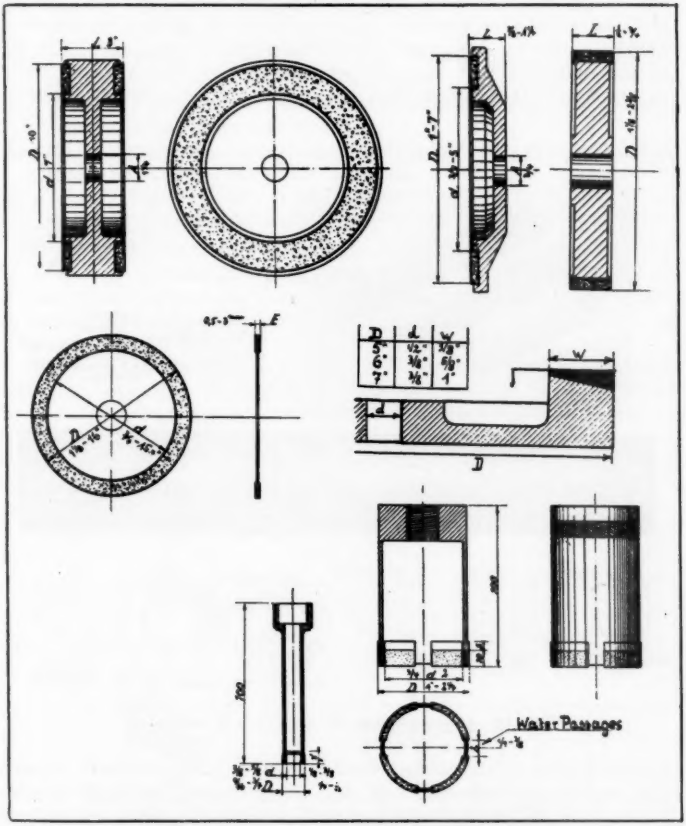



**Fig. 9.—Diamond rotating tools; discs and crowns.**

synthetic products. A variety of such tools is shown in Fig. 10. For steel and cast iron the working conditions must be exceptionally good for diamond tools to be used to advantage.

Only *super-fine* finishing work can be carried out with diamond tools, and feeds may be between .01 to .1 mm./rev. (.0004 to

.004 inch/rev.) and the cutting depth no more than .02 to 0.6 mm. (.008 to 0.24 inch). Both depend upon the cutting resistance of the material to be machined. The surface speed ought to be not less than 200 m./min. (600 feet/min.) and on large diameters, i.e., copper slip rings, commutators, etc., speeds over 3,000 m./min. (10,000 feet) have been employed. In area the chip section varies from .0004 sq. mm. to .1 sq. mm. (0.0000064/0.00016 sq. inch). The life of the diamond tool may be between 100 to 200 working hours (a full month !) if speed, feed, depth of cut are correctly selected

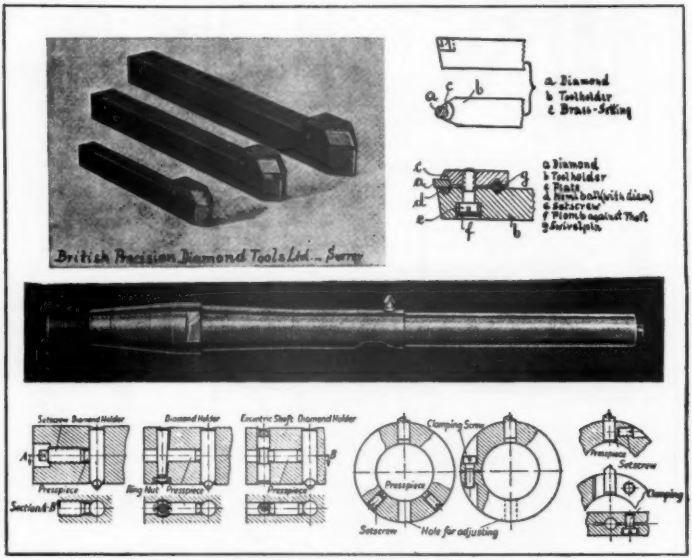



**Fig. 10.—Diamond tools for turning and boring.**

and the tool is well treated. Whether diamond tools can be economically employed, however, can only be decided for each exactly known case, the most severe competitor being the cemented carbide tool with well-lapped cutting edges.

For about ten years aircraft and automobile engine manufacturers especially have used diamond boring tools. The diamond is sometimes of sphero-pyramidal form, the cutting edges, up to 16, being equidistant radially from the centre. The condition is determined by the spherical underside formation of the diamond and allows

complete rotation of a plurality of cutting edges which can be brought into the operative position successively.

Fig. 10 (below) shows the methods of securing the set-tool in the boring bar. Good working conditions are :—

(1) Cold-set Diamond tool ;
(2) Micrometer means of adjustment ;
(3) Easily readable graduated dials, indicating the extent of adjustment (.00005 in. to .0005 in.) ;
(4) Means for securely retaining the diamond tool, when performing heavy cutting operations ;
(5) Provision for the ready removal and replacement of the diamond tool without disturbing the adjustment ;
(6) A very rigid machine tool ;
(7) Very rigid tool holder and secure clamping in the tool post.

Every trace of vibration must be avoided. Working tolerances of .002 mm. (.00008 in.) may be maintained with a very fine surface finish surpassing that of a fine-grinding action. The built-in micrometer adjustment of the cutting facet reads directly to .0025 mm. (.0001 in.).

*The diamond hand lap* is a very useful tool to stone the cutting edges of cemented carbide tips, if roughing down pieces of steel on the lathe. This hand lap consists of a flat piece of bakelite either impregnated with or having a layer of diamond dust on the surface. A good quality of thin oil should be used when lapping. The edge is stoned without disturbing the machine at frequent intervals to preserve the cutting edge. A sharp edge is destroyed by the unavoidable enormous mechanical stress caused by the flow (cratering) of hard and tough chips. A notch parallel to the cutting edge (Fig. 11) of about .004 by .12 in. (.1 by 3 mm.) serves best as simple, effective and easily adaptable chip deflector.

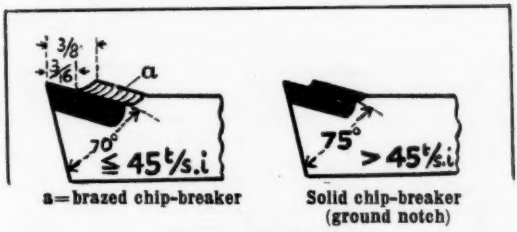
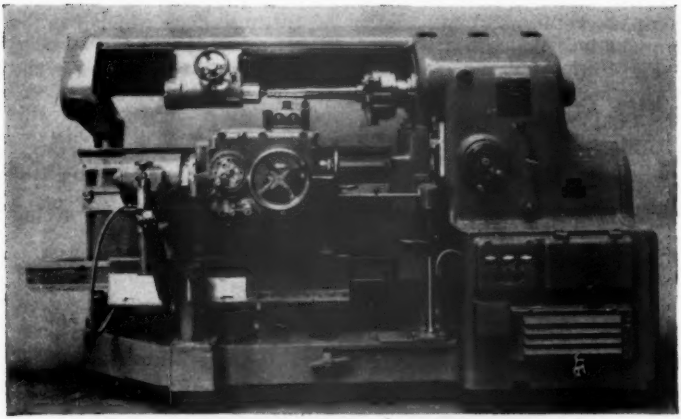
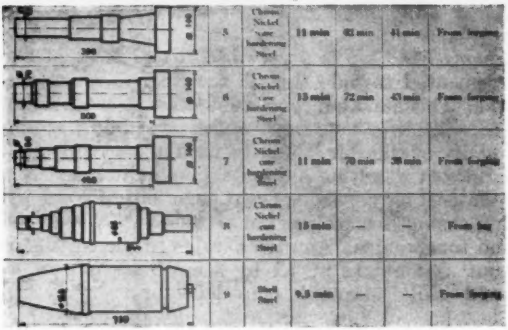



Fig. 11.—Chip-breaker.

**Rockwell—Hardness and Reheating Cobalt Tungsten Tools.**

Good cobalt-tungsten tools ought to show a hardness of about 64 to 65 on the Rockwell C scale and tungsten carbide tips about





| Work | Ex. sample No. | Material | Cutting Time: Rigid Lathe | Cutting Time: Normal Carbon with cutting speeds of Max. 18 ft/min | Cutting Time: Max. 22½ ft/min | Remarks |
|---|---|---|---|---|---|---|
| 360 | 1 | Chrom-Nickel case hardening Steel | 6.3 min | 38 min | 29 min | From bar |
| 320 | 2 | Chrom Nickel case hardening Steel | 13 min | 76 min | 48 min | From forging |
| 480 | 3 | Carbon Steel | 4 min | 19 min | 10 min | From bar |
| 360 | 4 | Carbon Steel | 16 min | 86 min | 56 min | From bar |

**Fig. 11a.—Rigid-turning-lathe (Fischer-Schaffhausen) and samples.**

85 to 92. Cobalt-tungsten tools reach maximum hardness only by reheating between 560° and 620°C., at least once and in some cases twice. The latest results with very good British, Swedish, and American tungsten carbides were obtained in December, 1938 (Brussels' Laboratory), with a rigid turning lathe of special design (Fig. 11a). The material used was cementable chromium nickel steel of Brinell Hardness 250, Brinell Resistance 75 Kg/mm², tensile strength 90 to 120 Kg/mm² (60 to 75 tons/sq. in.) the analysis of the steel being C=.15; Ni=3.6; Cr=.75; Mn=.4; Si=.3%. Cutting speeds varied from 360 up to 3,000 ft./min., with a roughing cut of chip section 2 by .4 mm. (.08 by .016 in.) and finishing cut of section .2 by .1 mm. (.008 by .004 in.). The accuracy reached was .01 mm. (.0004 in.) round and .01=per 400 mm. (.0004 to 16 in.) cylindrical. The finished appearance was perfect without any vibration marks.

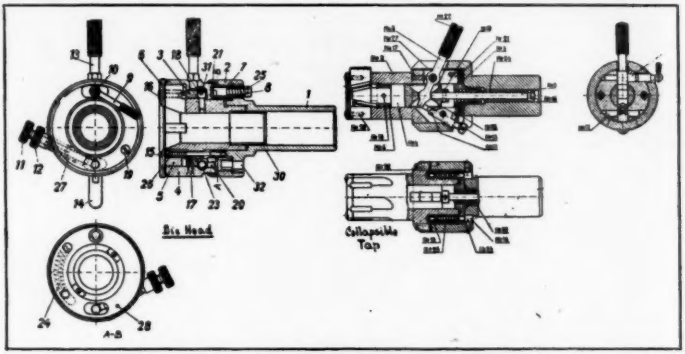


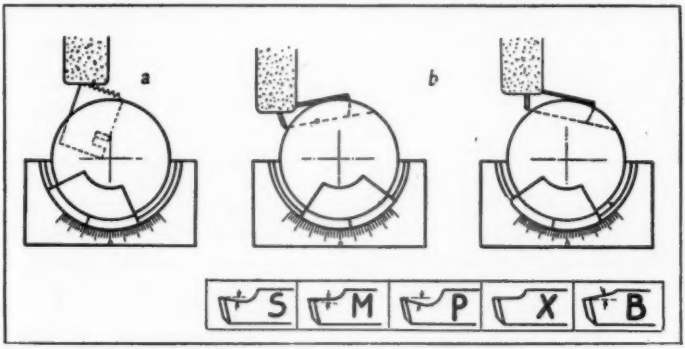

**Fig. 12.—Collapsible dieheads and taps.**

## Threading Tools.

Threading operations are a special province of turning, and die heads are now used even with small batches of parts. These tools are of the multiple cutting type, generally with four chasers cutting simultaneously. There are two different designs, as far as the cutting action is considered namely with radial and tangential cutters. Further, die-heads and collapsible taps may be of the stationary or the rotary type. (Fig. 12). The die-head parts are of heat-treated high carbon steel hardened and ground where necessary. They are mainly of the pull-off type, operated by arresting the travel of the turret slide.

Micrometer adjustment to .001 in. (.025 mm.) is provided and the setting can be repeated by foolproof mechanism at any time. This great accuracy demands precise cutting angles, altered to suit the

varying materials in a similar manner as with the single point cutting tools. We must have therefore a table of rake angles (Fig. 13). giving the angle of throat and the correct cutting angle. Because the




Grinding fixture adjustable for the variable cutting angles of the chasers:
*a* Throat.
*b* Cutting surfaces.

Short throat . =30–40°
Normal throat = 20°
Long throat . =10–15°

| Soft and forged steel 8–13° | Cast iron 0–5° | Copper 15° | Steels of more than 55 to s. in. 0° | Brass 12° |
|---|---|---|---|---|
| Malleable castings =8° | Bronze 0° | Alumin'm 15–20° | Tool steel 0° | Red brass 12° |
| Chrome nickel st'l 12° | | | | Electron 12° |
| Rustless steel 12–15° | | | | Delta metall. 12° |

**Fig. 13.—Grinding angles for chasers.**

shape of the finished chaser does not enable it to be held by hand, fixtures must be used to set the required cutting angle universally with regard to the grinding wheel. (Fig. 14).

The same brand of steel often varies considerably in machining properties. Then experiments are necessary with different cutting angles, if one given does not meet the particular case. We recommend for general work a throat angle of 20° and for tough materials 15°. There are two different methods of cutting threads: (1) Without a lead screw (usual way); (2) parallel cuts with a lead screw to control. Concerning (1), the non-cutting portion forms a hardened nut so that the pitch is controlled by its guiding action.

## Tolerances of Threading.

There must be for the material to be screwed either a full specification of the physical and chemical properties or better, generous

samples of material to enable the deliverer to carry out the necessary tests for finding the most suitable rake angle.

### Testing Set of Three Taps.

If a hole to be threaded is open on both sides it is good practice and most economical to use one single tap with a short throat, the teeth of which are perfectly ground. But if the hole is blind, a set of three threads is used for roughing out, pre-finishing, and final sizing. The cutting action is dependent only on the correct distribution of the turning moments to the three tools. A vertical thrust does not exist after having passed the tapered throat.

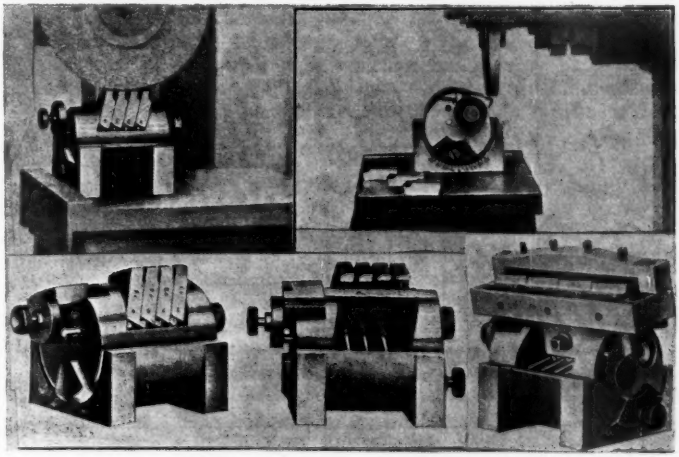


**Fig. 14.—Universal grinding fixture for chasers.**

The measuring apparatus (Fig. 15) consists of the main spindle of a drilling machine—*a*; driving clutch—*b*; tap—*c*; driving drum—*d*; constant weight (down thrust)—*e*; measuring table—*f*; clamping jig—*g*; manometer (pressure gauge)—*h*; recording drum for graphs—*i*: 2R=Diameter of drilling table; PP= forces against hydraulic pressure gauge. This autographic method furnishes graphs showing the moment depending on the depth of threaded hole (Fig. 16). Material tested was cast iron of 18 kg./mm.$^2$ (12 tons/sq. in.).

Two firms E and F sent sets of taps of 2½ in. Whitworth and 2¾ in. W. for testing. The graphs I, II, III, prove that the distribution of

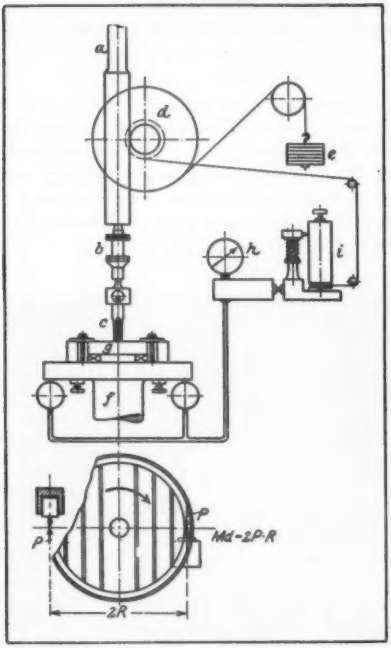



**Fig. 15.—Apparatus to measure directly cutting forces and torque.**

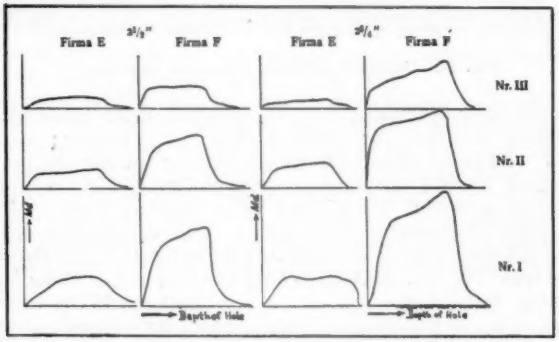



**Fig. 16.—Distribution of turning moments (torque) in a set of three taps.**

the cutting forces is about correct. In both cases tap No. 1 roughs the most material, tap II and III take considerably less. It is good practice to remove as much material as is possible with No. 1 and use No. III only as fine-finishing tool. The $2\frac{3}{4}$ in. tap sent by firm E proved best whilst the tap of grinding the firm F was in both tests very much worse than that of firm E. With the wrongly ground tap I —F $2\frac{3}{4}$ we almost destroyed the testing machine, whereas tap I—E $2\frac{3}{4}$ cut very easily.

### Twist Drill (Fig. 17)

The simplest but most widely used tool with two simultaneously cutting edges is the twist drill. Correct grinding of the point, edges and centre is decisive. Even to-day with the general good quality tool steel (cobalt-tungsten) we find often twist-drills which are incorrectly ground. How extraordinary the efficiency of a correct point can be compared with wrong grinding may be proved by publishing recent tests*. The output of the same drill under exactly the same working conditions was increased in the ratio of $\frac{290 \text{ holes}}{25 \text{ holes}} = \frac{11.5}{1}$ merely by regrinding the point (Fig. 17).

Fig. 17 (1) demonstrates the original (.....) grinding A and the reground (————) edge B.

Fig. 17 (2) shows the methods of measuring the angles of the point $\alpha =$ clearance angle, $\beta =$ wedge angle ; $\gamma =$ rake determined by the relief at different cylinder diameters.

Fig. 17 (3) is a graph illustrating the very uniform power consumption in watts from the sixth to the 272nd hole.

Fig. 17 (4) shows the relation between speed and power.

Fig. 19 (5) shows relation between speed and length drilled.

Fig. 17 (6) shows the distribution of Rockwell-hardness Rc. from the softer shank, which is elastic, Rc/d. = 42 to the much harder cutting part with the very uniform hardness Rc./cb. = 62. It was an interesting fact to find that the cutting edge itself for a depth of ab. = 0.1 in. had become blue after the fifth hole, that the hardness at point " a " dropped to Rc. = 59, but that the drilling action was not at all impaired. All holes up to 280 had a good interior finish and varied only by 0.1 mm. (0.004 in.) maximum deviation. But not only the grinding of the edge but the whole shape of the drill, determined by the angle of flutes, the angle of point and the relief are of importance.

Fig. 18 (1) shows the Stag-Major drill designed for machining manganese steel which has the disagreeable feature of work hardening. Thus, if the drill gets blunt, it will harden the inside wall of the hole and then break the drill much more easily. Short and stiff

* *Geo. Schlesinger—"The Engineer"—Cutting Angle of Twist Drills, Dec. 9, 1938.*

drills of correctly ground edge made of super-high-speed steel which do not bend or yield under torsion are the solution.

Fig. 18 (2) illustrates tests to find the right shape of tool to drill very soft " Elektron " metal. The task was to design small drills

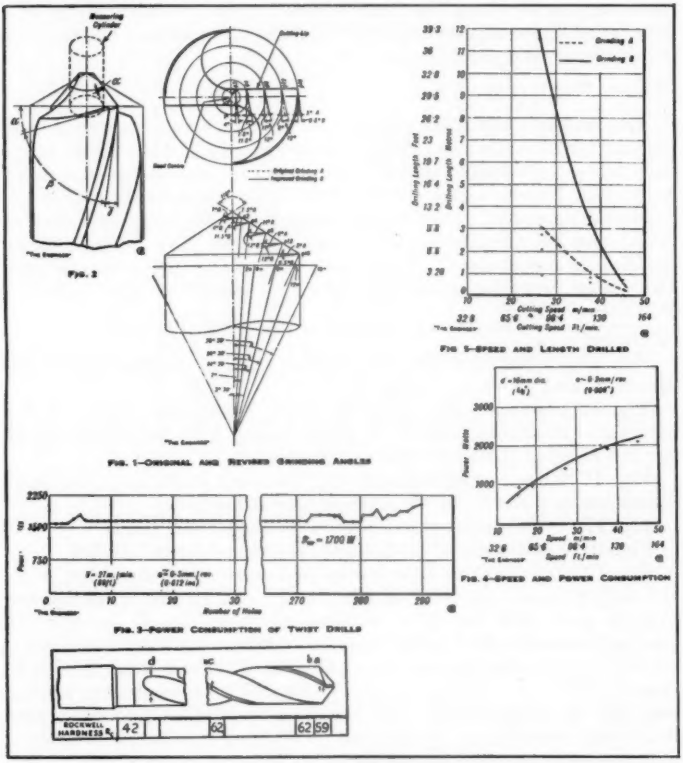



**Fig. 17.—Cutting angles and efficiency of twist drills.**

between 0.15 and 0.5 in. for deep holes, with at least a length of 10 diameters and to avoid the drill sticking, which always causes a breakage.

Four different flutes from 12°-24°-36°-45° angle of spiral and four different points with 80°-100°-120°-140° inclination have been tried. The turning moments do not differ, they rise up to 30 Kg. cm.,

but the thrust varies from 110 Kg. down to 25 Kg. (250 to 55 lb.) and reaches a very uniform value. This is then the best designed drill.

Point angles from 80 to 140° combined with 24°—flute-angle gave unsatisfactory results. The drill, driven by a constant pressure between 16 and 18 Kg. (40 lb.) stuck at 25, 35, 48 mm. (1, 1½, 1⅞ in.) depth, whereas a drill with 45° flute angle advanced easily to 10 × diam. (50 mm. = 2 in.) depth. With the 80° point the cutting time was 1.8 sec., with that of 140° 5.5 sec. With an increase in the ratio of 3 : 1 without risk of breaking the very fine drill, the shop economy is considerable.

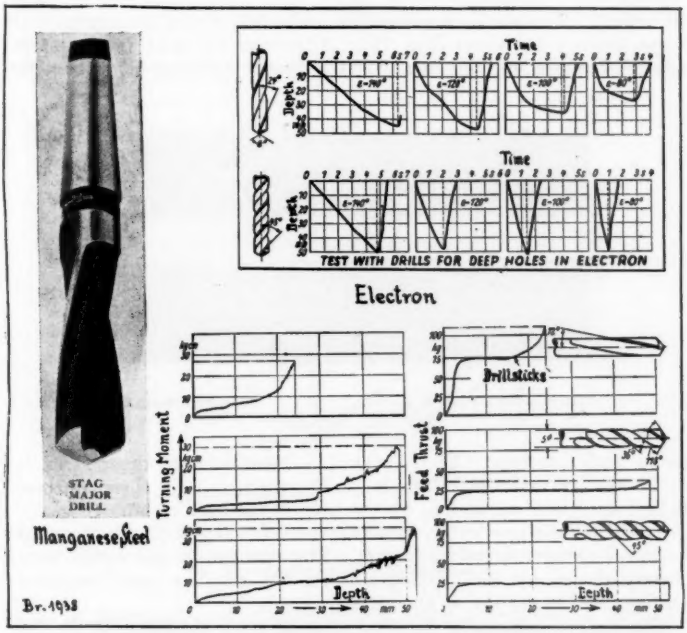



**Fig. 18.—Special forms of twist drills for very hard manganese steel and very soft electron.**

## Milling Cutters

This tool with multiple cutting edges, but with only a few actually cutting, is amongst the most difficult in the shop. Correct drilling is dependent on the fulfilment of the following conditions :—

(1) Milled surfaces must be accurate within the prescribed limits according to dimension and form.

(2) The surface finish must be absolutely clean.

(3) The tool used must have the longest possible life.

(4) The time of work ought to be as short as possible (maximum feed and speed).

(5) No chatter or vibration, and no irregular feeding are permissible.

(6) Power consumption must be as low as possible.

Some of these conditions contradict each other, therefore we must skilfully try to find the best compromise. A good cutter mounted on the arbor ought not to be more than 0.05 mm. (0.002 in.) out of round. The surfaces are rough and torn, if the eccentricity of some teeth is too great (Fig. 19). After regrinding all teeth to less than 0.025 mm. (0.0001 in.) eccentricity the surfaces (a, c) become

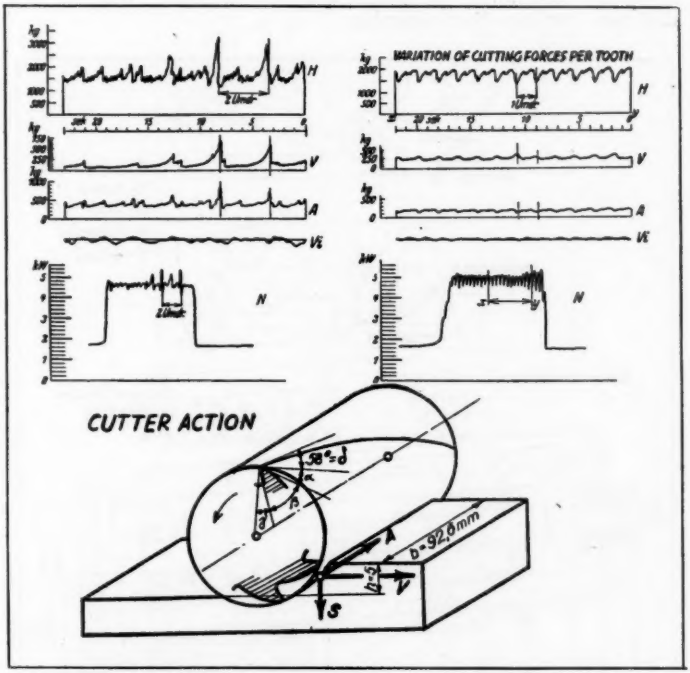
Cutter ground—round a, c Eccentric teeth b, d
Fig. 19.—Surface finish of milled surfaces.

clean and accurate. The working accuracy of good surfaces is 0.025 to 300 mm. (0.001 in./ft.). Investigation of these cutters before and after regrinding by the help of the oscillograph (Fig. 20) proved that the new cutter had two teeth too big (left) which could be rectified by regrinding (right). The undulation per tooth very clearly shown by the oscillograms on the left has been rendered uniform in the graphs on the right.

The testing apparatus allowed of measuring simultaneously the forces: H = horizontal, V = vertical, A = axial, Vi = vibration of the table surface, N = total power.

To avoid any lifting action by the vertical component, which might occur with deep cuts and a certain inclination of the teeth (angle $\delta$ Fig. 20) and further to decrease the feeding power (H) the down-cut milling has been developed in recent years. The upper views in Fig. 21 illustrate the principles of down-cut and up-cut

milling and especially the change of the point of attack and of the direction of the forces V and M as well as of H compared to the feeding force. Further, the two-spindle design is shown (below) to eliminate any back lash between nuts and spindles in feeding *with* the material. It would take an entire evening to discuss the advan-




Cutter with two big teeth. Cutter only .001 in. eccentric
Fig. 20.—Cutter action—oscillograms.

tages of down-cut and up-cut milling. We will therefore confine our remarks to the tool itself and the working conditions which are very complex.

The " variables " for the machining operations mentioned are :—

(1) *The workpiece* : material, machinability, form, clamping, accuracy, surface.

(2) *The tool* : material, design, diameter, cutting edges, angles, durability, quality.

(3) *The process of machining*: roughing, finishing, piece, mass-production, service.

(4) *The chip formation*: width, depth, feed, speed.

(5) *The machine tool*: numbers of revolutions, of feeds, suitability, quality, chucking apparatus.

(6) *The coolant*: composition, quantity, pressure, delivery and drainage, cooling effect, cleaning.

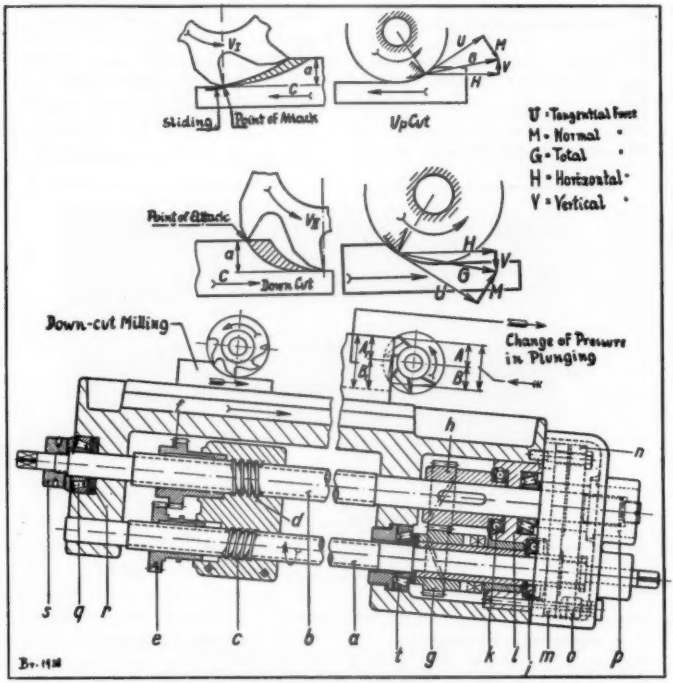



**Fig. 21.—DOWN-cut versus UP-cut milling.**
**Principle (above). Design (below).**

As it is impossible to fulfill all requirements we have to find the optimum solution for each special case. At a time when very great prominence is given to the expression output/efficiency in the entire technical world, empirical values alone no longer suffice, nor can the preparation of work be carried out by rule of thumb. This fact is firmly recognised to-day by all production engineers. It means

| In'ry No. | Type of machine | Maker | Main dimensions | Place | Age | | | Adapt. | | Costs of adapt'n | Price of new mach. | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | before war | Aft'r war | Aft'r 1932 | No | Yes | | | |
| 504 | Grindg. mach. ... | U.S.A. | HC. 6¼ in. | Hall B3 | • | | | • | | £ — | £ 500 | Scrap. |
| 503 | Millg. mach. ... | England. | Betw. C. 30 in. Table 10 × 35 in. | ,, B3 | • | | | • | | — | 600 | Still useful. |
| 507 | Grind. mach. ... | Germany | Mvt. 40 in. Table 52 × 12 in. | ,, B3 | • | | | | • | 70 | 580 | Magn. chuck. |
| 605 | Millg. mach. ... | U.S.A. | Mvt. 70 in. Table 36 × 10 in. | ,, 6 | | • | | | • | 60 | 600 | |
| 606 | Millg. mach. ... | U.S.A. | 5 h.p. Table 30 × 8 in. 3 h.p. | ,, 6 | | • | | | • | 45 | 480 | Aut. vert. mort. |
| 603 | Millg. mach. ... | U.S.A. | Table 25 × 7 in. | ,, 6 | • | | | • | | — | 75 | Old hand miller. |
| 610 | Millg. mach. ... | U.S.A. | Table 40 × 10 in. | ,, 7 | • | | | • | | — | 560 | For light work. |
| 613 | Millg. mach. ... | U.S.A. | Table 55 × 12 in. | ,, 7 | | • | | | • | 75 | 800 | Strong mach. |
| 1205 | Radial drill pr. ... | U.S.A. | Spdl. ⌀ 4 in. Rad. mor. 40 in. | ,, 17 | • | | | | • | 50 | 750 | Univ. adjble. |
| 2084 | Hor. borg. mill. ... | Germany | Spdl. ⌀ 3¼ in. | ,, 17 | • | | | | • | 90 | 900 | |
| 2711 | Centre lathe ... | U.S.A. | HC. 14 in. Betw. C. 15 ft. | ,, 17 | | • | | | • | 95 | 1000 | |
| | Adaptation or new machine. | | | | | | | | Tot. | £485 | £6845 | |

Fig. 22.—Repair—rebuild versus expenses for new machine (economic comparison)

naturally that the work of each is rendered much more difficult, and his responsibility increased. Who, however, has the time and opportunity to descend into the "dark pits of theory" until his feet encounter firm ground in order to build up therefrom the requisite knowledge for himself?

That would also be a very uneconomical proceeding. "Division of Labour" is therefore necessary. Experimenter—designer—production engineer all work for each and each for all. They work together for the common good, and each is backed by the experience of others. But all build on the same basis, and every technician knows that scientific research alone can support the edifice of our practice. The fundamental rules of the manufacture and checking of machine tools are well known, they form the indispensable basis for the machine tool *maker*.

The *user* must proceed differently. He must consult his balance sheet. There may be sufficient funds to renew the existing plant or replace some of the old machines only. This demands an economic study which is made on the basis shown in Fig. 22.

(1) Machines which are adaptable to modern conditions.

(2) Machines which are not adaptable; worn-out; obsolete.

Then we distinguish by the broad periods.

(1) Before the war.

(2) After the war.

(3) After 1932.

Further, one must examine or have an expert examine these points:—

(1) What is the real state of the different machines?

(2) How much will it cost to repair or rebuild them?

(3) What is the price of the new machine to replace the old one?

Some remarks concerning specially bad or good qualities will facilitate the final decision. The final addition gives the expenditure for: (1) Simple repair. (2) Deeper overhaul. (3) Rebuilding and modernising.

Then you know how much to pay and how long it will last to rebuild or to purchase new machines.

## Discussion.

MR. J. R. SINCLAIR (*Section President, in the Chair*) : The meeting is open for a short discussion.

MR. TIPPLE : I would like to say how thoroughly I have enjoyed Dr. Schlesinger's lecture to-night. The ground he has covered has probably been too wide, but I would like to make one or two comments. I cannot understand why Dr. Schlesinger states that a cutting tool should be set $^1/_{32}$ in. above the lathe centre. Surely altering the height of the tool in the standard centre lathe only modifies slightly the top rake and the front clearance of the cutting edges.

DR. SCHLESINGER : When roughing with the tool on centre the tool may break down and is now presented to the work below centre, consequently the tool has a tendency to pull in. On a finishing cut the tool can be set on centre.

MR. TIPPLE : Thank you very much. Whilst I cannot agree entirely with your remarks, they certainly offer an explanation. I note that radial tools have been shown in nearly all illustrations, but I think that tangential tools are found to give better results where it is possible to use them, as the whole of the cutting pressure puts the tool in compression throughout the shank without any bending moments.

DR. SCHLESINGER : For tangential tools in a lathe you must have a rigid tool post ; and many machine tools have not.

MR. TIPPLE : I was surprised to hear Dr. Schlesinger refer to the production of work from forgings and then show it was cheaper to produce from the bar using tungsten carbide tools. Whilst this is true, surely it is better to continue to use forgings and obtain still further increases of production by using tungsten carbide tools on the forgings. Work which has been produced by forging gives a better material, whilst very often the grain flow can be modified and a much stronger forging obtained.

DR. SCHLESINGER : The prime costs consist of the costs of material plus wages plus overheads. Generally, in forging overheads amount to 400% on wages and in machining only 150%. If the material is expensive I would prefer to forge, but good forgings, i.e., stampings, are only practical for at least 100 pieces, and not for one to 10 pieces as would mostly apply in machine tool production. You must not always think of the automobile industry. To rough hand-forged work pieces with cemented carbide tools is a bad combination. There is often a difference of up to $\frac{1}{2}$ in. in diameter in pieces from the forge ; the scale is also bad, and the tool tips may split when first contacting the piece.

MR. TIPPLE: Unfortunately Dr. Schlesinger has been referring to hand-made forgings, whilst I am referring to machine-made forgings or, in other words, drop stampings or die stampings. Naturally I was alluding to production on a relatively large scale. It must be remembered that the function of the machine is to produce work and not to produce chips; whilst it will always be found more costly to cut a given weight of material into a very large number of chips than it is to produce the same weight of chips of a larger size.

"Down-cut" milling has been referred to, and this has certainly been brought to the fore recently, although many articles were written on the subject about fifty years ago. It is true that in "down-cut" milling the cutter is tending to pull the table and work along, but I would not like anyone here to-night to imagine that the saving in power is very much because of that. Actually the horse-power required to drive the feed of a milling machine is only approximately 10% of that required to drive the cutter, and the saving can only be in the feed drive—not in the cutter drive.

Dr. Schlesinger laid great stress on the formula :—

$$HP = \frac{P \times V}{21{,}000.}$$

This we shall all recognise is being the same as saying that the horse-power is equal to the number of foot pounds per minute divided by 33,000, but instead of the 33,000, 21,000 is used. This is apparently a means of allowing an efficiency of the machine of 66%, which figure, I think, is approximately correct.

The pressure "P" on the tool was investigated in 1902 by Nicholson and Smith at Manchester Municipal School of Technology, and by Taylor in the United States about the same period, and I have known since that date that the pressure of a lathe tool was approximately 70 tons per square inch of chip area when cutting cast iron, 100-120 tons per square inch of chip area when cutting mild steel of about 35 tons tensile, and 150 tons per square inch when cutting annealed gun steel. Smith and Poliakoff also made extensive tests and published results in 1909 of the torque and thrust when drilling various materials at varying speeds and feeds. I have designed large machine tools and calculated stresses on gears and shafts and horse power required, using Nicholson and Smith's experiments as a basis, for over thirty years.

I quite agree with Dr. Schlesinger that the resultant pressures on the arbor and work are different when "down-cut" milling, compared with the conventional method. It is also apparent that the force required to drive the cutter at its periphery produces a reaction on the table of the same magnitude which has to be overcome by

the feed mechanism. The cutter, however, may be assumed as moving at about 60 feet per minute, whilst the table is only moving at one foot per minute, in which case the horse-power to drive the cutter will be 60 times the h.p. required to drive the feed, assuming 100% efficiency in each case. The feed mechanism has screws, worms and wormwheels, mitre wheels, etc., all tending to make for a relatively low overall efficiency, and generally this efficiency is found to be no more than 16%. If we, therefore, assume that the efficiency of the main drive is six times greater than that of the feed drive, then we arrive at our conclusion, which is substantiated in practice, namely that the h.p. to drive the cutter is approximately 10 times that required to drive the feed.

MR. TIPPLE: In conclusion, I would like to thank Dr. Schlesinger personally for giving us such an interesting and profitable lecture to-night.

MR. DRANE: Has Dr. Schlesinger made any tests with chip breakers?

DR. SCHLESINGER: Several chip breakers have been tried, but when you have a small block welded on the top of the tool, the chips can still curl before breaking. I would recommend that a small notch be ground at the front of the tool, 1 m/m. to 4 m/m. wide, and 0.1 to 0.3 deep (see **Fig. 11**) which can be regulated to suit the material.

MR. SINCLAIR: I very much regret pressure of time does not permit us to spend longer over this discussion. I could personally listen to Dr. Schlesinger for a long time. I feel what Dr. Schlesinger has told us has not only been instructive, but extremely interesting, and I consider it has given us a lot of food for thought. I therefore ask you to join me in thanking Dr. Schlesinger for a very interesting lecture to-night.

# WORKS MANAGEMENT FOR THE SMALL FACTORY

*Paper presented to the Institution, Eastern Counties Section, by P. G. Robertson, A.M.I.P.E.*

IN preparing my paper I have dealt with the subject from the production point of view and have not embodied any matters relating to the purely financial side of the question. In any manufacturing organisation there is a great diversity of opinion as to the best method of procedure. If we turn to books we can find many admirable volumes dealing with the subject but most of them treat of the larger undertakings. The small factory does not seem to get the same attention, and yet, as has often been stated in this Institution, it is generally more difficult to organise and control a small factory than a large one.

The management problems of the small factory, which I think we may roughly define as employing from 75 to 350 persons, are of a different nature. We do not find, in most cases, that we can settle down comfortably to the manufacturing of one class of product with a plant laid down for that purpose and suitable to the demand made upon it. We generally find—and I am speaking of engineering shops—that we either have too much work or not enough. We manufacture in batches of 10, 50, or 100, and very often one or two of special machines or appliances. New orders and repeat orders are received from day to day and are usually wanted the day before yesterday.

Here, then, we have the conditions ruling in most small engineering factories and our problem is to establish an organisation and a system to deal effectively with them. What staff do we require to handle the business efficiently? Too often in the small factory the staff is not adequate. In others it is overburdened with unskilled personnel on the technical or administrative side. Certain essential work has to be done and done properly if we are to achieve any fair measure of success.

Let us examine what I believe are essential parts of our organisation and consider how best they may serve our requirements. For our purpose we can broadly divide our analysis into five parts: (1) Design—the drawing office and its related work; (2) labour—estimating, planning, ratefixing, progressing, jigs and tools, inspection, plant, and equipment; (3) materials, buying—stores; (4) works costs; (5) general considerations.

*Ipswich, November 1, 1938.*

We will commence with the drawing office as that is usually the genesis of the product from the manufacturing point of view. What does the drawing office exist for ? I have heard that question asked in many different forms. Draughtsmen are necessary evils. The function of the drawing office is to prepare designs of new products and to translate customers' requirements in a manner that can readily be understood in the shops. The latter is often the most difficult task. The drawing office can be a most effective force for the easy management of a works from both a technical and administrative viewpoint or it can be the reverse.

Drawings should be prepared in a manner that will give the shops full information in the form they require it. Normally, the more information on the drawing the less questions asked and time lost. In this regard one often sees drawings smothered in dimensions and the figure required in the shops has to be worked out by the man or the foreman. When calling for tapped holes give drill size or letter. When putting limits give figures, not letters, for various fits. Study the setters' and operators' requirements and put down the figures and angles they want to do the job. Examine the design to see if it can be made on existing plant without employing excessively costly or freak methods. It may be possible to modify it. Keep a list of all screws, bolts, studs, etc., held in stock, bar sizes, angles, and flats. If possible use them. It will reduce the storekeeper's worries and the capital sum tied up in stock. I know of a case where 27 kinds of bracket were in stock, when a little ingenuity could have reduced it to one. In fact we did eventually use only one.

When the drawings of a job are complete we come to the schedule. This schedule is, in my opinion, of the utmost importance in facilitating the easy working of the factory. It should be complete down to the smallest screw or washer, exact in its details of part numbers, number of and description and finish of part and precise in its specification of materials. In its reputation for thoroughness it should be the one document whose accuracy cannot be challenged. I repeat that from every point of view it is of prime importance.

A word on drawing numbers or part numbers. Many offices number drawings with a prefixing letter denoting size of sheet, figures denoting series or type of machine and the actual numerical party number tacked on, e.g., Y42923 where Y is the size of sheet, 429 is the serial number and 23 is the part number. This system is all right for the drawing office purpose but can be made more useful to other departments.

In keeping to our resolve to make the drawing office information the fullest possible the part number can play a useful part. The system advocated is this ; a letter to indicate the size of sheet, a letter series to determine the type of machine or unit and a part

number of particular definition, e.g., $\overline{\text{3JB749}}^{\text{Y}}$. Y denotes the size of sheet for filing purposes, 3JB denotes the type of machine (the three indicates the third model or series) and 749 the part number. The 749 is taken from a standard table, thus :—

| | | | |
|---|---|---|---|
| 1 to 99 | ... | ... | Gunmetal or brass castings and bars |
| 100 to 199 | ... | ... | Aluminium, etc. |
| 200 to 499 | ... | ... | Iron castings |
| 500 to 599 | ... | ... | Steel and malleable castings |
| 600 to 699 | ... | ... | Special steels, etc. |
| 700 to 899 | ... | ... | Steel bars and flats |
| 900 to 1000 | ... | ... | General materials |

By this means the part number tells at once the kind of article being dealt with. A part 749 is known to be of steel bar and the cost office will not cost it as an iron casting. It tells the size of drawing to look for, the kind of machine it is for, whether old or new type, and the nature of the material it is made from. It does everything but make the job for you.

Drawings should be mounted on millboard and cellulosed, not issued as pieces of paper. Loose paper prints are easily damaged, obliterated, or lost. A careful check should be kept on all prints issued to shops so that amendments can be positively made. In a properly managed factory it should be made impossible for incorrect prints to exist in any part of the organisation. It is advisable to issue prints to a store and have them returned there at the completion of the job.

A word on the personnel of the drawing office. The drawing office is the major technical department in the small factory ; therefore, the staff must be up to its work. It does not pay to employ cheap labour in the drawing office any more than it does in any other department where you are paying for brains and not brawn. Your draughtsmen must be shop trained men who know their job. Encourage them to go into the works and see the difficulties encountered and the methods employed. If possible, bring them into touch with the customers. It widens their outlook and prevents them from getting stale. Finally, have a sufficient drawing office staff to keep everything up to date and give time for clear thinking and proper consideration of detail. It pays.

**Estimating, Planning, and Ratefixing.**

When we have produced our design, or have an inquiry, we have to fix a selling price or, in other words, estimate for the job. Competent estimating is one of the corner stones of the successful factory. Bad estimating can easily ruin an otherwise properly organised business ; yet we find in many small factories that the estimator is a person who has graduated from sales office boy,

with no practical training and little technical ability. "*Guesstimating*" would be the more correct term to use for his work. This position is even more deplorable when the office of planning and ratefixing is combined with that of estimating. For our estimating, as in all other departments, we must have a practical engineer and a man of ability. He must be able to size the job up an know whether the factory can tackle it successfully. He should confer with his colleagues and the foremen in the works and produce an estimate that will get the order and show a profit. If he cuts things too fine in order to get the work he will probably be invited to come into the works and show how to do the job at his figures. Enquiries must be dealt with promptly. Too often the job is lost, not on price, but due to delay in quoting.

In a small factory there is not usually such a spate of enquiries and new work that we can afford to keep separate and distinct departments dealing with estimating, planning, and ratefixing. Personally, I think that they can with advantage be combined into one staff as they are all closely related. In preparing our labour estimate we must cover some of the ground of both the planner and the ratefixer. For our estimate to be successful, from an internal point of view, it must be a fairly accurate forecast of what will take place in the factory. To get an order you must give an estimate but you can execute an order without preplanning and this is very often done. It is left to the shops and trouble is the inevitable result.

The chief duty of the planner is to examine every component carefully and decide the methods to be adopted to make that part from start to finish. To do this a thorough knowledge of the capabilities of the plant and equipment is necessary. It may be that while a part can be made in the factory, it could be purchased as a finished or semi-finished article at a more economical figure because other firms have more suitable plant or specialised machines. The planner in the small factory should always bear this in mind when examining new work. I know there are objections to this policy, but it you can buy a part for about half the price it would cost you to make, why make it ?

In preparing layouts for the shop, they should be complete in every detail ; nothing should be omitted. When a layout is issued no departure from it should be allowed without reference to and sanction from the planner and records altered accordingly. Otherwise the job will rapidly get out of hand. It is a wise thing to review old layouts as work is sent in to the factory. However good the procedure was, say, two years ago, it may be possible to improve it. New tools, new machines have come into being during that time. Always be on the lookout to improve the method ; it can usually be done.

The drawing and the layout are both required in the shop at the same time, therefore, it is found advantageous to mount a copy of the layout alongside the drawing. You then have the whole story of that part ready to hand ; the shape of it, the material it is made from, the method of procedure, the jig fixture and gauge numbers, and the time allowed per operation. The object, of course, is to reduce idle and waste time in finding the information by workmen or staff. I know there will be objections to this method, but if as I have already stated, we keep a close check on all copies of drawings existing in both works and offices we should have little difficulty in making any amendments or corrections that may be necessary.

When the precise methods of manufacturing a part are decided, the rate or time allowed should be fixed before the work is issued to the shop. Although this may seem an obvious procedure it is very often omitted, especially when the factory is engaged in making a large variety of parts in small numbers. The argument is that due to short runs, frequent change-overs, getting tackle and tools, etc., you cannot get jobs down to the same basis time on successive occasions. The answer is that you cannot charge a customer another 5s. because Bill Jones mislaid his special holding-down bolts for that job, or that the section labourer had gone to find his broom and that you could not lift the job without him. The estimator has to fix his price on time and there must be a time in which the job can normally be done. The ratefixer and foreman must arrive at that time and see that it is worked to.

For this reason piece-work is unsatisfactory in the small works unless the product is on repetition lines, because the rate is forced up to cover all contingencies. Equally a flat hourly rate is not desirable because there is no incentive to the worker to put more energy into the job than he is obliged to. A bonus scheme of some kind is, I believe, generally accepted as necessary to obtain economical production. In operating any form of bonus scheme the rate fixing must be reasonably accurate; abnormally high bonuses indicate lack of knowledge of the conditions on the part of the ratefixer. Ratecutting leads to a general feeling of distrust and opposition on the part of the men. If necessary, the job should be demonstrated before the rate is fixed in order to get accurate figures.

To be successful a bonus scheme should be simple and readily understood by the operators. Complicated and involved methods of arriving at bonuses should be avoided as operators will distrust them and trouble and arguments will ensue. Straight bonus on time system is one that I favour. Paid on individual output it does not always operate satisfactorily if you are dealing with many varied jobs as one unfortunate operator may get a run of bad jobs and his neighbour the reverse, thus causing discontent. A collective bonus

system is in my opinion the best where it can be worked conveniently. It has one great advantage in that it engenders a team spirit and a spirit of co-operation which is a tremendous advantage to the efficient working of a small factory where supervision is necessarily less than in its larger counterpart. Slackers and dodgers are not tolerated by their fellows. Foremen and chargehands are chased up from both ends to keep their men supplied with work and, if you bring the foreman also into the scheme, you will find some better chasers among them than in the progress department.

**Progressing.**

No matter how carefully the planning department have done their work or how exactly the rates have been fixed to produce the job, there must be a motive force to put it through the factory. That motive force is the progress department. It is a department that should receive generous support from the works manager, as the efficiency of this office reflects directly on the good management of the factory and on the monthly accounts. Its staff may be one man or more according to our needs. The progress department commences its duties immediately a job is required to be put into the works. Working from the schedule issued from the drawing office they find out from the storekeeper what materials are in stock and instruct the buyer what to purchase. The progress man acting directly under the works manager should be the only one to say how and when a job shall be put through the factory. It is his job to route the work in such a manner as will bring a series of components to completion at a given time and enable the assembly shop to pick the job up and finish it outright. How often does a partial assembly take root and even bloom while waiting for that small part that everybody knew of but nobody worried about. He should keep the works manager informed of all overdue orders and the reasons for same, orders outstanding due to raw material, idle machinery, excessive scrap, or viewroom rejects and generally all outstanding matters affecting the flow of work in the shop. He can be, as I said, a vital force or just a " chaser " in the worst sense of the word ; and unless he has a programme to work to that is all he will be. In the early part of this paper I mentioned that every job was wanted at once and under these conditions it is possible for the progress men to work like niggers and accomplish nothing. They may get hundreds of parts ready all lying in the finish store and very few completed jobs going out of the door.

Here the necessity for the progress programme arises and it is a feature of management well worth consideration. It is, in short, to fix an objective that is to be reached in a given period of time. In so doing the activities and energies of the progress department and everybody concerned are focussed on a common aim. The

objective is a certain monthly output in terms of cash. This sum is the minimum output per month to keep the factory on a sound basis. The progress programme is compiled by the works manager and the progress and sales departments in such a manner as will make it possible to reach the desired total. Some customers make more noise about delivery than others. Material deliveries and other snags will occur but the programme should be capable of covering these troubles. It should be clearly understood that the monthly total is the minimum required, but can be exceeded. I have known of cases where the required output for the month has been obtained and other work held back by the progress man to ensure the output for the succeeding month. This is unnecessary because any figure above the minimum can, if required, be brought forward to the next month so far as the progress department is concerned. A scheme of this kind definitely puts an end to haphazard chasing and keeps a pointer on the trend of the factory, informing the management of the state of affairs before this becomes " history."

## Jigs and Fixtures.

The use of jigs and fixtures for manufacturing any quantity of articles has become an integral part of shop practice. So much so that it is becoming increasingly rare to find operators who can make anything without these aids. To ensure interchangeability, rapid and cheap production they are essential. It is common practice in some small factories for jigs to be designed and made in the tool room from the component drawings. This, in my opinion, is not a satisfactory procedure. You may on the surface be saving the cost of a jig and tool designer but you invariably pay more for the jigs and do not get the best in design. A jig drawn on the board can be altered by a few strokes of the pencil but you cannot rub out a half made jig on the bench. All jigs and tools should, therefore, be properly designed and considered in the drawing office but the draughtsman should be a practical man and thoroughly acquainted with their making and operating. Design the jigs to suit the class of operator. This point can greatly affect the cost of a jig. A simple form of jig may work well in the hands of a competent man but if entirely unskilled labour is used then every eventuality must be catered for. Much attention must be paid to the loading and unloading of a jig to obtain economical production. You probably have seen many jigs that function like a child's money box. You can put the part in easily enough but to get it out requires a lot of ingenuity.

All jigs and tools should be kept as simple as possible ; elaborate and intricate mechanisms should be very carefully scrutinised and

their merits weighed. The value of an order and the possibility of a repeat must be considered before commencing tooling up, otherwise the cost of the jigs may swallow up any anticipated profits. Jigs are an expensive item in manufacturing and as such should be controlled in the shops like any other job. A price should be fixed and kept to within reasonable limits.

The small factory is not always properly equipped for the economical and accurate production of jigs and tools, and in such cases it is better to have them made outside. Although the average tool-making firms know how to charge for their products, you can always send them back if they are not right, and you have the satisfaction of knowing precisely how much the tool cost you. The main trouble in outside purchasing is, of course, getting delivery.

All jigs and fixtures should be demonstrated and a component machined from them should be handed over to the inspection to be passed before going into production. It is also advisable for all jigs and fixtures in constant use to be periodically inspected by the tool-room and worn bushes, etc., replaced before trouble occurs in production.

## Inspection.

Inspection is perhaps one of the biggest bogies existing in the small factory. Many of the smaller ones run without any official inspection at all. It is looked upon as an expense that should not be necessary and when inspection is employed it is cut down to the lowest limit and the people engaged upon it are of the wrong type. In my opinion it is both a necessary and a worth while expense. It saves trouble and money internally and externally. Nothing is so disastrous as faulty or badly finished work leaving the factory. Equally disastrous from an economic view point is faulty and inaccurate work in the shops and entering the shops from outside sources as raw material. Money is spent on successive operations when the part has been scrapped in its early stages and not detected. The fitting and erecting shops are full of troubles due to faulty work from the machine shop. It is axiomatic that if quality is controlled, quantity looks after itself. If you are to control quality you must have inspection. To have foremen and chargehands viewing their own work is never satisfactory, for obvious reasons.

The size of the inspection staff depends entirely on the nature of the product being manufactured and the class of labour employed. The chief inspector should not be a man who has to rely largely on his own initiative but should be working to clear instructions given by the drawing office regarding limits and quality of finish desired. A properly qualified inspector is a very useful man and

should be paid as such. He should report to the works manager periodically as required but should be given a free hand to do his job and to exert his authority.

## Plant and Equipment.

The problem of plant maintenance and replacement and the purchase of new machines is one that continually exercises the powers of the average works manager of a small factory. If the business is old established he usually has 80% of his machines of pre-war, or in many cases pre-flood, vintage and most of these with one foot in the scrap yard.

New plant costs money, and while I agree that we cannot hope to clear out all the relics at one go, it should be, in my opinion, the active policy of the management to replace with new machines progressively.

The maximum production obtainable and the limits possible on all machines should be tabulated together with their capacities. An accurate record of maintenance charges against each machine should be kept and with these tables and a knowledge of the demand made on each type of machine we can review the economy of replacement. Modern tools and new cutting alloys require modern machines, and present day competition requires us to use every time saving device possible. Nevertheless, whatever the age of the machines, they should be periodically inspected and overhauled if necessary. It is bad policy to wait until a breakdown occurs ; it may happen at a most awkward time, and of course serious damage may be done both to the machine and to the operator.

## Materials—Buying.

The buyer in a small factory is usually a non-technical and a non-practical man. There is no objection to this, in my opinion, provided he is told precisely what to buy. The information with regard to quality and specification should be provided by the drawing office on the job schedule. The information regarding quantity should be provided by the progress department who will check up with stores to determine which items can come from stock and mark them on the job schedule that they send to the buyer. They will also tell him what delivery he must strive to obtain.

The question of the price he pays for the material is his responsibility, but he and the estimator should collaborate to ensure that the figure in the estimate is covered by his purchase price. The purchase price of each item should be entered on the job schedule and sent to the costs office. It should be kept in mind that the

lowest price is not always the best price. If you are getting something cheap there is usually a snag in it somewhere. Cheap castings and bars ultimately cost more than the better grade materials in wear and tear of the cutters and tools, etc.

The important thing for the buyer to remember is that materials are required at a certain time, that the factory has planned to use them at a given date and that the dislocation caused by non-delivery, or only partial delivery, usually costs a great deal more than the few pence saved initially. Overtime may have to be worked to counteract the loss of time due to late delivery of raw materials and thus increase production costs. So many buyers place orders for goods to be delivered at a given date and if they are not forthcoming regard it as unfortunate but in no way reflecting on them. I think that the problem is entirely theirs and that according to the measure of success they have in solving it so their efficiency as buyers must be judged.

It is customary in some firms for the urging of materials to come from the progress department. In this case if material is not delivered the buyer may say " I was not asked for it," thus putting the onus on the progress department. Personally, I favour the policy of leaving the buyer with full responsibility in the matter, and although he will get promptings from other sources he knows it is up to him. He will probably be more circumspect in choosing his suppliers if he has to carry the " baby."

**Stores.**

Materials are purchased with money. Money is guarded with scrupulous care and every penny spent is recorded and accounted for as a matter of course. Yet materials (i.e., converted money) are in many cases treated in an astonishingly haphazard manner in many small factories. No one would dream of putting the office boy in charge of even the petty cash of the firm, but when it comes to stores anyone with two hands to move the stuff around will do. This may sound an exaggeration but it is true in a great many instances. People dealing with materials should be trained to think of them in terms of cash and treat them accordingly. This being the case, all stores should be strictly controlled, and nobody unauthorised (workmen or foremen) should be allowed in there. Stockcards should be kept in the bins of all goods, and movement of stocks in or out should be recorded. It is an advantage to have a chart on the end of the bins showing the location and content of individual bins.

It is common practice to write a requisition for all materials required from the stores. This is usually done by the foreman of the department for either raw material, finished parts, or general stock. In a small factory our aim is to reduce the amount of clerical work as far as possible.

To do this, material is issued against the schedule of the job compiled by the drawing office. This schedule, you will recall, is complete to the smallest detail. The schedule is sent to the stores by the foreman together with a progress slip which is his authority to draw materials. The required quantity is marked up on his schedule and material schedule and slip are sent back to him. The quantity issued is entered on a copy held by the storekeeper who also records the weights if necessary and marks off his stockcard. General materials only such as files, hacksaws, rags, etc., are issued against written requisitions. Re-issue of material due to loss or scrap may only be made against written requisition and the scrapped parts returned to the stores at the same time. This scrap can be put into a special location and the works manager may pay periodical visits to the stores and see what scrap is occurring and where it comes from. On completing an operation or a part the foreman sends the job, schedule, and slip back to the stores and the number returned is checked against the issuing figure on the schedule and the schedule is returned. Any discrepancies can be checked up at once and accounted for.

I had experience with one firm of a system that entailed the writing of a requisition each time a part was drawn from the stores for an operation and the writing of a credit note each time is was returned. In a very short period there were dozens of notes relating to each part and the number of papers ultimately became so great that they were just waste paper. Nobody could find time to check them.

The system advocated keeps the clerical work down to a minimum in the shops. I expect you have all had experience of trying to decipher requisitions written in haste in the factory with wrong descriptions and wrong part numbers. If the storekeeper can add up correctly, excess materials cannot be issued and the final quantities can be checked at once and not be a matter of investigating ancient history. The storekeeper's master copy for raw material is ultimately sent to the costs office or it can be checked up at any given period as required.

## Works Costs.

In small factories we find varied attitudes towards costing systems. In some a ponderous and complicated method is followed. In others there is practically no detailed costing system at all; undoubtedly a great deal of money can be spent in this department to procure figures of one kind or another. The value of some of the results obtained is problematical.

I do not propose to deal with the assessment and allocation of overhead charges. It would need a paper on its own and quite a number have already been given on this subject. For our purpose

these figures are fixed and our works costs rely on two factors —viz., direct labour and direct material. We have dealt briefly with the control of material and the method of returning accounts of the raw material issued by the stores. Using the stores schedule of raw material issues and the buying schedule giving purchase prices, we can assess our prime material costs with reasonable accuracy and no great difficulty. It remains then to collect our labour figures.

I would here say definitely that no time sheets, job cards or any other sheets should be written out by the operators themselves. The practice of letting them do so is far more common than one would suppose. With every good intention we can never hope to get accurate returns with this means; and if the returns are not accurate they are worse than useless—they are misleading. I also think it is wise to avoid getting large numbers of loose cards or sheets travelling in the works. The more there are the greater the liability of error or loss. For the small factory the simpler the means of collecting information the better. Whatever system we adopt there will always be snags and loopholes. We have yet to find the perfect method.

One scheme that I have worked with fair success is to have daily or weekly sheets for each operator. These are in the charge of a clerk situated in the factory. When the progress department want a part put in hand a slip is made out quoting order No., part No., operation No., and quantity required, and is sent to the foreman by whom it is sent to the stores with the job schedule, and the material is obtained. When the operator commences work the slip is sent to the booking clerk who records the time and the job on the man's sheet and returns the slip to the foreman. On completion of the job the schedule slip and material are sent to the viewing stores and from there the slip is sent to the booking clerk who records the number done and the time off. The time off is, of course, the time on of the next job which the operator commences immediately a completed job leaves him. The clerk keeps the slip and sends it to the progress department, who are thus kept informed of the movement of all parts. The costs office receive the daily or weekly sheets, allocate the various entries and assess bonus payment. The total prime labour cost can be made up when the progress department report that all work on a particular order has been carried out.

Having obtained our prime costs for materials and labour we can make up our works costs and compare them with the estimated figures and the works manager can express his satisfaction or otherwise as to the results.

**General Considerations.**

We have dealt with the major functions directly connected with production, but there are subsidiary considerations that have a great bearing on the efficiency of the factory. One of these is general cleanliness and orderliness. Although this matter has received a good deal of attention in large works it is not always so in small ones. A dirty shop produces a careless attitude of mind in the operator. Litter and waste on the floors, boxes, crates and equipment in odd corners, little attention to clear gangways, work dumped in any clear space produce an atmosphere more like a street market than an engineering factory. Apart from the question of hygiene, to produce work of quality under these conditions is a doubly difficult task.

Heating and lighting are now receiving much needed attention due in part to the activities of the factory inspector, as also is the provision of safety devices. In my opinion it pays to make working conditions as safe and trouble free as possible. If workmen are injured even in a minor way their productive efficiency is impaired and the firm lose thereby. Safety devices and measures are good, but we will always have to contend with the human element. As with road users, we can try to enforce safety, but it is better to train people to think safety. To this end an accident poster should be put up on the notice board, and the nature and cause of all accidents, however slight, should be clearly stated for all to read. These details will in time be impressed on the minds of the employees and avoid a repetition of similar occurrences.

In dealing with labour in a small factory we have, I think, an advantage in that more personal contact is possible between the men and the executives. This personal touch is valuable in that it makes men feel that they are more than mere adjuncts of a machine. They should be made to feel that they are part of a team. This team spirit is well worth cultivating as it increases the personal efficiency of every one in the works. The essence of the team spirit is respect for the leaders, from the foremen upward. This respect is founded on an appreciation of the knowledge of the superior and his qualities as a man, with regard to fairness and firmness. In this connection I think there is nothing more detrimental to the enthusiasm of an employee than the habit, common enough among people in charge from the lowest to the highest, of continually pointing out very forcibly the errors, omissions and mistakes made and refraining with equal presistance from ever giving a pat on the back or a word of praise for a job of work well done.

These remarks apply very pointedly to the leader of the team —the works manager. The works manager of the small factory has, in my opinion, to be a man of both technical ability and practical

experience and to have or acquire a detailed knowledge of every activity under his jurisdiction. He is constantly under the necessity of making decisions on widely divergent problems, from the drawing office onwards. The number of his higher executive staff is small and this being the case he is well advised to engage men of ability and not consider getting the lowest priced men he can to fill the posts. If he pays a bit more than he thinks he ought to give he will, if he has got the right man, find it a very good investment.

The main thing the works manager has to keep in mind is the fact that he is the focal point of the whole works organisation. As he deals with matters, so will his staff. If he allows the continued pressure of events to make him slack off, to hedge his responsibility, to put off decisions or to lose some of his pep and enthusiasm his staff will undoubtedly react in the same manner. While all the crew unite in running the ship, the Captain sets the course and the success of the small factory depends in a very marked degree upon the wisdom and leadership of the man in charge.

## Discussion.

MR. WOODS asked the lecturer what he considered to be a small factory.

THE LECTURER replied that a small factory would be one employing from 75 to 350 persons.

MR. A. LEGGETT (*Section President, who presided*): Is this figure of 350 from personal experience, or is it generally understood that this number of employees would constitute a small factory?

MR. ROBERTSON: I have seen many estimates of the number which could constitute a small factory. On one occasion I saw a table that stated that 80% of the factories in this country employ less than 75. This number would comprise little more than a workroom. I think that anything from 75 to 350 would be a reasonable number.

MR. WHITE: It was mentioned at the beginning of the lecture that there should never be more than one copy of a drawing in the works. I do not think this could be done, as often machine operators would have to wait until the drawing could be found.

Again, when the schedule sheet is issued, I think it should be someone's business to go through the material required to see what is in stock and what should be ordered.

MR. ROBERTSON: I do not recall saying that only one copy of the drawing should be issued to the shops. What I said was that careful check should be kept on all drawings in the shops so that they could always be found. With regard to finding out what material is in stock, the progress man, when he gets his schedule, goes to the storekeeper and finds out what is in stock. When his schedule is marked up he sends it to the buyer and tells him what to buy.

MR. R. E. DUNNETT: During the course of the paper Mr. Robertson showed some preference for a collective bonus scheme instead of individual effort. He went so far as to include the foremen in this scheme. I knew of one or two occasions where such a scheme has had to be dropped because the foreman planned the work to suit his own pocket. Of course, in choosing a foreman, one would choose a man who would not do these things. However, I would like to have Mr. Robertson's opinion on this, and whether he has met with any such experience.

MR. ROBERTSON: I have tried daywork, piecework, individual payment and collective bonus, and the one we are paying now is the collective bonus with a bonus paid to the foreman. With piecework, if you are in a factory producing a variety of products, you have to dig very deeply into ratefixing. Daywork does not give any

incentive to the men. With the individual bonus scheme there are many uses this can be put to ; it is a case of clocking the time on the job and the men being paid on numbers. There have been cases where the numbers paid for have not gone into the finished part stores and, sometimes, bonus has been paid on stuff which has never been made. All operators fall into one category ; they are paid a certain percentage of the entire bonus based on their earning or day rate, or hourly rate fixed. If a man is paid 1s. 9d. or 2s. per hour, he is more valuable than a man paid 1s. per hour and he is entitled to a larger percentage in accordance to the rate he is paid. When you get a scheme of that kind working, if one operator sees another slacking down he is carrying him on his back and he tells the slacker to get on with it. One individual operator cannot gain at the expense of another. With regard to the method of bonus to foremen, they do not participate in the actual bonus earnings of the men ; they are paid a bonus on the percentage total reduction in hours per week on the job, and bonus is paid on getting the work through the shops to time. This bonus is paid monthly. In this way the foreman acts as a good chaser.

MR. LEGGETT, JUNR., asked if travelling inspection paid—that is, inspecting the parts in progress. Also, is overtime economical ?

MR. ROBERTSON : With regard to the first question, if a fault is noticed while parts are going through a process they may be scrapped in the middle of that process. The Chief Inspector is a man who has a roving commission and can inspect any part in process or coming into the factory. He is the proper person to view any work in process. Other than that, if a blowhole occurs when a part is being machined, the foreman or charge hand should find this out.

With regard to overtime, I think that overtime does not pay, because when the people have done eight and a half hours in the factory, their efficiency begins to tail off, and if you have kept any check on overtime output, you will know that it does not come up to expectations. I regard overtime as an emergency measure. If the capacity of the plant will not yield to requirements, I advocate employing more men to build it up and get work into the sections done by people who can do the job efficiently.

MR. D. BRAID : I would like to know if the lecturer has any method in mind of getting the utmost output from the inspection staff. Very often they just appear to be roving about and not doing their job.

MR. ROBERTSON : It is rather difficult to employ any method for getting the utmost out of an inspector because to inspect one casting may take half an hour, and when you get another casting of a similar order it may take an hour and a half to inspect. Nobody can say what time an inspector will take. Inspection, to my mind,

is not really a job for an operator. Inspectors should be people who can be trusted. On a repetition job it is possible to fix a time for all inspection operations.

MR. C. H. WOODS: Do you cover alterations to plant which are not interchangeable, and also, how do you cover fabricated parts? They have to be something before they are joined together.

MR. ROBERTSON: With regard to parts which have been mended, these will go back into the schedule of parts. If you have a fabricated part and you are using cold rolled angles and flats, the individual component parts steel, will bear the definition such as mild steel and have the appropriate number. If you have an assembly, it will still bear the same definition.

MR. J. B. WEBSTER: To whom should the chief inspector be responsible for rejects—to the foreman, works manager, or some other authority?

MR. ROBERTSON: To my mind, the chief inspector should be a man who is responsible to the works director in the case of a large factory. With regard to a small factory, the chief inspector should be directly responsible to the works manager.

MR. LEGGETT, JUNR.: With regard to the collective bonus, does this apply to unskilled labour?

MR. ROBERTSON: The skilled and unskilled workers come under the collective scheme. The method of paying them is on the basis of the percentage of their earning capacity. If the time fixed for a job is ten hours and it is done in eight hours, 50% of the difference goes into the bonus pool and 50% to the employees' fund. If a job rated at ten hours takes twelve hours, 50% is taken from the mens' pool and 50% from the balance which is accruing. The bonus is paid weekly.

MR. LEGGETT, JUNR.: In the case where twelve hours is taken to do a job which should be done in ten hours, and one is very much quicker than the other, is it right that he should still carry the slow man along?

MR. ROBERTSON: The efficiency of the individual is no part of the collective bonus scheme; if a man cannot make bonus his rate is dropped. If a man continually makes bonus above the rate, his rate is increased. Therefore, the method of paying for efficiency is by increasing or decreasing the rates.

MR. H. J. COPPING: On behalf of the Eastern Counties Section, I should like to say how much we appreciate Mr. Robertson's coming along and giving us his paper. Mr. Robertson says that the buyer could be a non-technical man. I think he should be a technical man, because in these days he has to see representatives of different firms and he should know just what is wanted. With regard to material numbers, I think myself that the makers' symbols, when you have so many types of steels, are much easier to use.